Adoption and Meaningful Use of Computerized Physician Order Entry With an Integrated Clinical Decision Support System for Radiology: Ten-Year Analysis in an Urban Teaching Hospital

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Purpose: The aim of this study was to assess whether an integrated imaging computerized physician order entry (CPOE) system with embedded decision support for imaging can be accepted clinically.

Methods: The study was performed in a health care delivery network with an affiliated academic hospital. After pilot testing and user feedback, a Web-enabled CPOE system with embedded imaging decision support was phased into clinical use between 2000 and 2010 across outpatient, emergency department, and inpatient settings. The primary outcome measure was meaningful use, defined as the proportion of imaging studies performed with orders electronically created (EC) or electronically signed by an authorized provider. The secondary outcome measure was adoption, defined as the proportion of imaging studies that were ordered electronically, irrespective of who entered the order in the CPOE system. Univariate and multivariate regression analyses were performed to estimate trends and the significance of practice settings, examination modality, and body part to outcome measures. Chi-square statistics were used to assess differences across specialties.

Results: A total of 4.1 million imaging studies were performed during the study period. From 2000 to 2010, significant increases in meaningful use (for EC studies, from 0.4% to 61.9%; for electronically signed studies, from 0.4% to 92.2%; $P < .005$) and the adoption of CPOE (from 0.5% to 94.6%, $P < .005$) were observed. The use of EC studies was greatest in the emergency department and inpatient settings. Meaningful use varied across specialties; surgical subspecialties had the lowest rates of EC studies.

Conclusions: Imaging CPOE with embedded decision support integrated into the IT infrastructure of the health care enterprise and clinicians' workflow can be broadly accepted clinically.

Key Words: Health care information technology, computerized physician order entry, decision support, health policy

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INTRODUCTION

Over the past 4 decades, advances in diagnostic imaging have revolutionized the practice of medicine. These advances have enhanced physicians' understanding of diseases and contributed tremendously to patient care [1]. Along with these benefits, imaging studies also carry costs [2]. In 2008, imaging services expenditures totaled $11.7 billion among Medicare beneficiaries [3]. Between 1998 and 2001, the utilization of MR, CT, and ultrasonographic imaging studies per Medicare enrollee increased by 8.3% to 16.6% annually [4]. Similar trends were

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observed in private insurance groups and individual institutions [5,6]. In addition to expanded clinical indications, potential driving forces for imaging growth include defensive medicine, uncertainty or knowledge gaps among ordering physicians about imaging indications, self-referral by physicians, diagnostic uncertainty, a lack of availability of prior images, the aging population, and patient expectations [4,7-10].

Promoted by the Obama administration, the widespread adoption of electronic health records and computerized physician order entry (CPOE) has become an important cornerstone of national health care policy [11]. These systems may be a means to improve quality and to reduce health disparities [12-16], and their use in clinical practice has been associated with improvements in medication safety, efficiency, physician ordering patterns, and cost reduction. To catalyze the national adoption of electronic health records, Congress passed the Health Information Technology for Economic and Clinical Health Act as part of the American Recovery and Reinvestment Act of 2009 [17]. The American Recovery and Reinvestment Act also authorized CMS to provide financial incentives for providers who successfully implement "meaningful use" of technology, including CPOE [18].

Initial experience shows a promising impact of CPOE on some physician imaging ordering practices [19]. Despite growing evidence of its benefits, CPOE adoption has been slow, with only 9.6% of US hospitals having CPOE completely available [20]. Increasing the percentage of imaging orders clinicians place via CPOE yields important opportunities to expose them to decision support (DS), potentially reducing waste and improving quality of care [21]. The aim of this study was to determine whether an integrated imaging CPOE system with embedded DS can be accepted broadly by clinicians in day-to-day practice. We also aimed to identify major predictors influencing adoption and meaningful use.

METHODS

Study Population and Site

The study included all diagnostic imaging studies performed between January 1, 2000, and June 30, 2010, in our health care delivery network. Our facility consists of a 777-bed, university-affiliated tertiary care hospital with 44,000 inpatient admissions, 950,000 ambulatory visits, and 54,000 emergency department (ED) visits accounting for >500,000 imaging studies annually. The institution's outpatient network spans >183 practices with 1,200 physicians. The requirement to obtain informed consent was waived by the institutional review board for this HIPAA-compliant study.

The Radiology Imaging Order System

The system is a Web-enabled CPOE system for imaging (Percipio; Medicalis Corporation, San Francisco, California). Before its implementation, all studies were ordered using paper and telephone methods. Office staff members, nurses, physician assistants, residents, and staff physicians are permitted to place imaging orders using the CPOE. Upon entering a password-protected login, the physician or a proxy creates orders for a specific study from predetermined structured menus (Figure 1). Patients are identified by unique medical record numbers. Each CPOE session captures all relevant information necessary to specify a requested imaging procedure, including clinical indications for the examination [21]. On the basis of the inputted data, the CPOE system will launch real-time DS to aid the requesting personnel in choosing the best diagnostic strategy, if such evidence is available. The DS generation is dependent on the particular examination, patient, and clinical context and presentation. For example, an order for an abdominal radiograph in a patient with suspected appendicitis triggers a "low-utility" message with a recommendation for a higher yield examination (Figure 1C) [22]. When faced with the DS, clinicians may choose to cancel the request or proceed with the order, and adherence to the DS recommendation is voluntary. The CPOE system generates e-mail notification twice daily to ordering providers who have unsigned orders created by nonphysician proxies, prompting the ordering providers to log into the CPOE system to electronically sign the orders before the examinations can be performed. Users can access this signature queue from their computer desktops or their preferred mobile devices.

All providers within the health care enterprise have access to the ordering system. The great majority of providers outside our health care network and their support staff members have not been given access to the system and continue to call a central scheduling office to request radiologic examination. Although these offsite providers were included in the analysis, they account for a small portion (<5%) of radiologic examinations performed at our institution.

Integration Into the Organization's IT Infrastructure

From 1998 to 1999, design, prototype development, pilot testing, user feedback, and integration planning were undertaken to ensure that the CPOE system was well integrated into the IT framework of the health care enterprise. Radiology CPOE was gradually phased into clinical practice in 2000, starting in primary care physician offices and subsequently rolled out to all outpatient clinics, the ED, and inpatient units through 2006. During and after the implementation, paper requisitions and telephone scheduling with faxed requisitions continued to be alternatives to CPOE.

Before rollout in each care setting (outpatient, ED, and inpatient), a standards-based integration project was undertaken to launch the radiology CPOE system from the electronic medical record platform used in that care setting. We used servlet, ActiveX interface, and Web shell token technologies to integrate various clinical applications. The integration enabled users to launch the radiology CPOE system from within each of the 3 electronic medical record platforms in the context of the user and the patient, thus eliminating duplicate administrative data entry by users (Figure 2).

Workflow Optimization

Over the course of implementation, informal feedback was sought from users. Subsequently, a variety of user requests were developed into features and functions of the radiology CPOE system by the vendor (Medicalis Corporation) to optimize workflow, with examples described below. The CPOE system was integrated into an enterprise radiology resource-based scheduling module, which enabled ordering providers or their proxies to schedule radiologic examinations online at any radiology provider's facilities within our network (without the need to place a phone call), irrespective of the radiology information system in use at the radiology practice. Order integration to the radiology information system at each site used standard Health Level 7 messaging to optimize communication of order information from CPOE to radiology systems. *International Classification of Diseases,* ninth rev, coding of structured indications displayed in CPOE ordering menus (Figure 1B) enhanced data collection for billing processes. More recently, integration of the CPOE system with third-party payers' preauthorization databases reduced the preauthorization burden in the ordering providers' workflow when possible. Some of these features were added and modified during the broad implementation phase as a result of user feedback.

Outcome Measures

The primary outcome measure was meaningful use of CPOE, defined as (1) the proportion of all imaging examinations performed with orders electronically created (EC) by authorized providers in the CPOE system or (2) the proportion of all imaging examinations performed with orders electronically signed (ES) by authorized providers after the orders are initially entered by proxies (eg, office staff members) in the CPOE system. The secondary outcome measure was adoption, defined as the proportion of examinations with EC orders in the CPOE system irrespective of who entered the orders the system (an authorized provider or a proxy). The institutional goal was >90% clinical acceptance in both adoption and meaningful use.

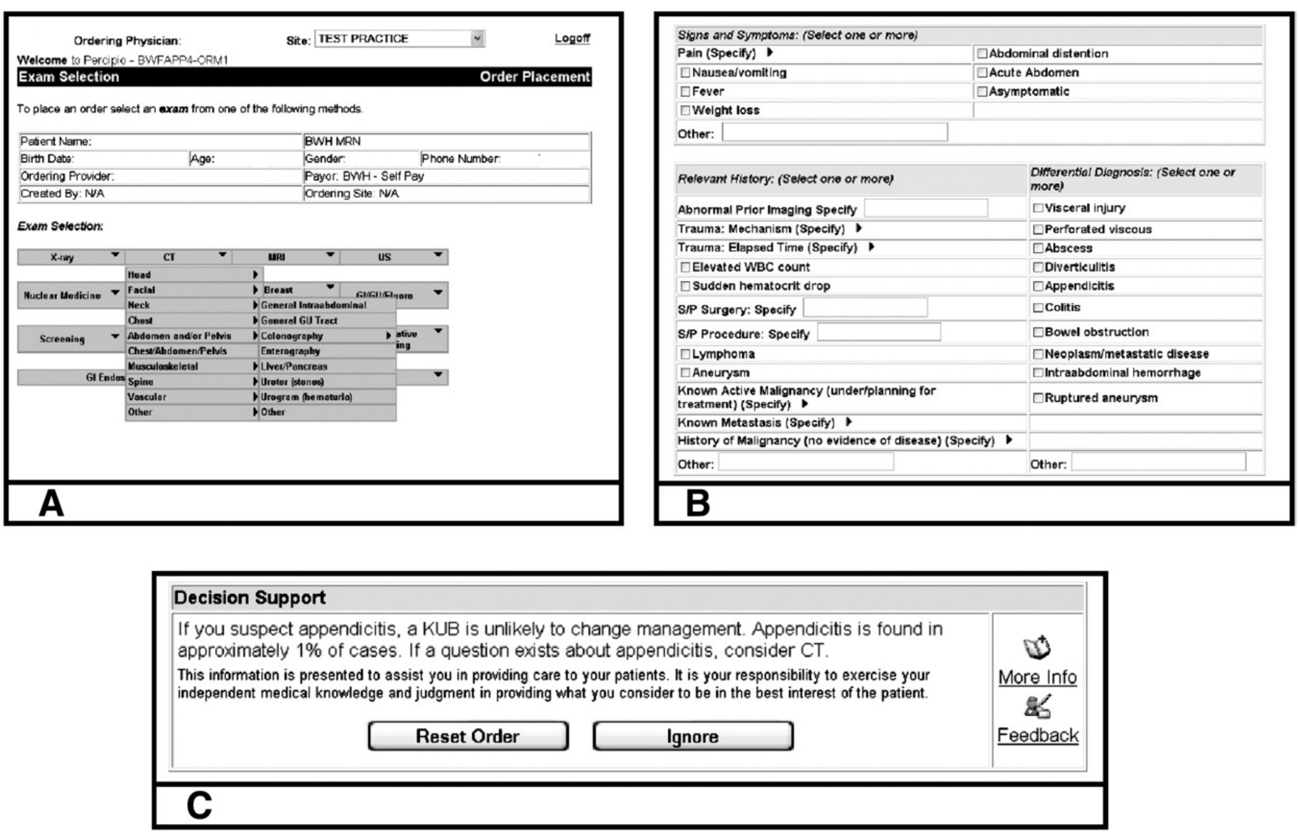

Fig 1. Screenshots of the computerized physician order entry system of examination selection (A), indication menu (B), and decision support (C).

Data Collection and Analysis

Data were collected during the early implementation (January 2000 through December 2001), broad implementation (January 2002 through December 2006), and post-CPOE implementation (from January 2007 through June 2010) phases. These time frames were somewhat arbitrary but generally refer to the implementation of CPOE by early adopters (early implementation), followed by broad implementation of CPOE, which was completed by January 2007. We compared the volume of all radiologic examinations requested in the CPOE system to the volume of examinations performed and documented in our institutional radiology information system (IDXRad version 9; GE Healthcare, Burlington, Vermont), after attempting to correlate each performed examination to an existing order on the basis of patient medical record number, imaging modality, study body part, and scheduled, ordered, and completed dates. Examinations that did not have correlating electronic orders were classified as having bypassed the CPOE system.

Only orders for performed studies were counted, using a single unique examination identifier (accession number) as the unit of counting. Data on electronic order creation and provider signature were collected directly from the CPOE system database.

Imaging studies were classified by imaging modality (CT, MRI, ultrasound, plain film, nuclear medicine/PET, mammography, fluoroscopy, and bone densitometry), body part (head and neck, chest, abdomen, pelvis, spine, breast, bone, extremities, and other), and practice setting (inpatient, outpatient, and ED). Information regarding the specialties of ordering physicians was also captured. We did not have access to databases for examinations performed by nonradiologists, including cardiac catheterizations and echocardiographic studies, so they were excluded from analysis, although these examinations are also ordered using the same CPOE system in our network. Because interventional procedures often require direct consultation with radiologists, these examinations were also excluded from the analysis.

Statistical analyses were performed using Microsoft Excel 2003 (Microsoft Corporation, Redmond, Washington) and JMP version 8 (SAS Institute Inc, Cary, North Carolina). Univariate and multivariate logistic regression models were fitted to investigate factors that may affect the rate of meaningful use (ES and EC orders) and adoption. Model covariates included 3 categorical variables (examination modality, body part, and practice setting) and 1 continuous variable (time in 6-month periods). Outcome variables were categorized as binaries of whether or not CPOE adoption and meaningful use (ES and EC orders) were applied. Chi-square tests were applied to the 2009 and 2010 data to determine differences across ordering physician specialties. Two-tailed P values $< .05$ were defined as indicating statistical significance.

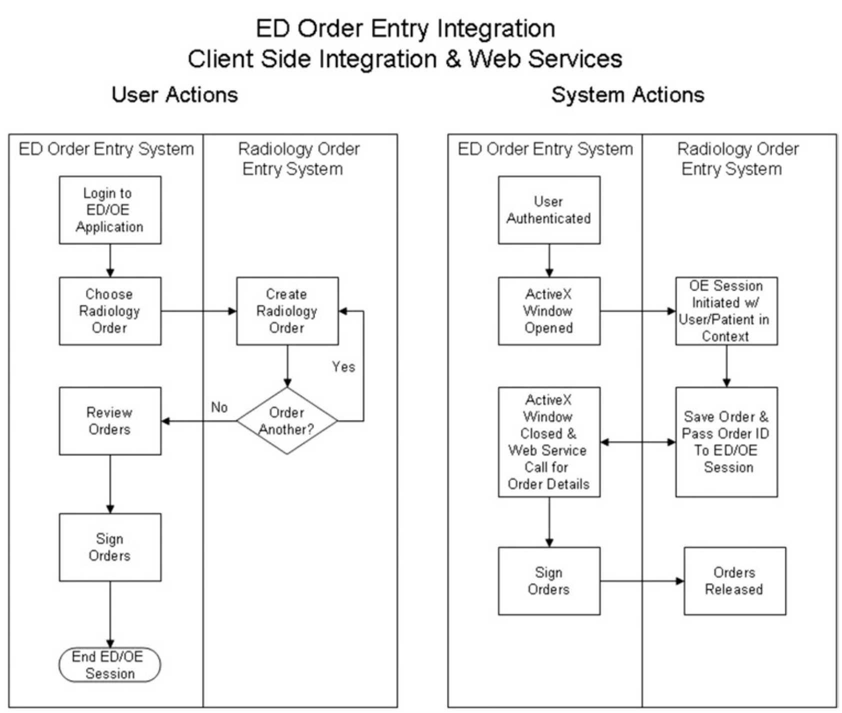

Fig 2. Example imaging computerized physician order entry (OE) integration into electronic medical record and relevant provider workflows. When orders are released, they are simultaneously scheduled in radiology such that the scanner is no longer available for subsequent orders at that time and date. ED = emergency department.

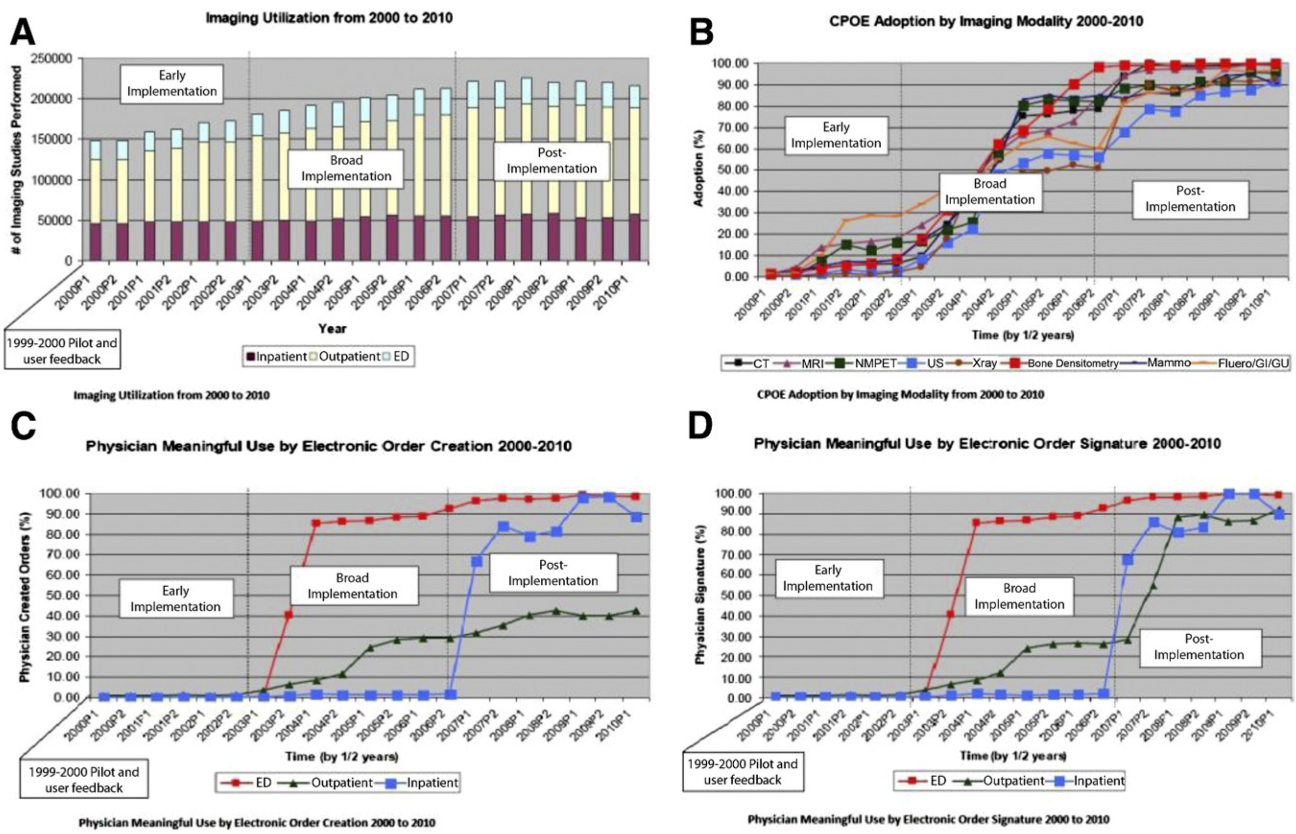

Fig 3. Trends of imaging utilization (A), adoption of computerized physician order entry (CPOE) system (B), physician meaningful use by electronic order creation (C), and physician meaningful use by electronic order signature (D) from 2000 to 2010. ED = emergency department; NM = nuclear medicine; US = ultrasound.

RESULTS

A total of 4.1 million diagnostic imaging studies were performed between January 2000 and June 2010. Over the interval, orders were requested by 14,899 unique users. We found a significant increase in the total number of diagnostic imaging studies performed semiannually, from 147,850 in 2000 to 215,920 in 2010 ($P < .005$; Figure 3A). CT, MRI, and nuclear medicine experienced the greatest rates of growth, at 117%, 328%, and 201%, respectively, over the study period.

Adoption of CPOE rose steadily, from 0.5% in 2000 to 94.6% in 2010 ($P < .005$). Physician use of CPOE was significantly different across imaging modalities (Figure 3B). CT and MRI were more likely to be ordered via CPOE than ultrasound, x-ray, and mammography ($P < .005$). Adoption of CPOE varied across practice settings, ranging from 89.8% in inpatient units to 99.2% in the ED ($P < .005$).

Meaningful use of CPOE also increased significantly ($P < .005$) from 2000 to 2010 (for EC orders, from 0.4% to 61.9%; for ES orders, from 0.4% to 92.2%). Meaningful use of ES orders in the CPOE system varied from 89.5% in the inpatient setting to 98.9% in the ED. Meaningful use of EC orders in the CPOE system also differed across practice settings, with outpatient providers being the least likely to generate the orders themselves (42.6%; Figures 3C and 3D). Use of EC orders was most prevalent among those who worked in primary care practices and the ED and least widespread in surgical subspecialties ($P < .05$). Obstetrics and gynecology, gastroenterology, orthopedics, and urology were associated with the lowest rates of meaningful use of EC orders ($P < .05$; Table 1). However, these same providers had high proportions of meaningful use of ES orders (>90%).

In the multivariate regression analysis, the 3 models converged without errors. The adjusted R^2 statistics from the regression were 0.57, 0.56, and 0.40, for CPOE adoption, EC orders, and ES orders, respectively. For each of these models, examination modality, body part, practice settings, and time were all statistically significant factors ($P < .005$). The estimated unit odds ratios were 1.7, 1.4, and 1.7 per 6 months for CPOE adoption, EC orders, and ES orders, respectively.

The workflow features most cited informally as helpful by our providers are listed in Table 2. The most valuable included the integrated online scheduling module, the ability to electronically sign an order created by a non-physician proxy from any preferred mobile device, and the elimination of duplicate administrative data entry. In addition, the ability to obtain preauthorization from

Table 1. CPOE adoption and meaningful use by setting and specialty

Setting/Specialty	CPOE Adoption (%)	Physician Meaningful Use of EC Orders (%)	Physician Meaningful Use of ES Orders (%)
Setting			
Inpatient	89.8	88.6	89.5
Emergency	99.2	98.3	98.9
Outpatient	95.8	42.6	92.0
Specialty			
Anesthesiology	94.2	91.1	94.1
Cardiology	90.8	57.0	90.7
Dermatology	99.2	92.6	97.5
Endocrinology	96.5	75.8	93.4
Gastroenterology	97.7	9.4	97.0
General medicine	96.1	94.7	96.1
Gerontology	98.0	91.3	98.0
Hematology	94.8	90.5	76.7
Immunology	97.1	94.0	96.3
Infectious diseases	94.6	88.4	93.5
Nephrology	94.7	90.2	94.2
Neurology	98.4	67.5	98.1
Neurosurgery	97.3	34.0	97.2
Obstetrics/gynecology	92.5	11.7	92.3
Oncology	97.0	65.3	96.7
Orthopedics	97.0	16.8	97.0
Otolaryngology	96.2	83.1	94.4
Plastic surgery	97.5	66.8	97.5
Primary care	95.0	80.0	93.7
Pulmonary	92.5	69.4	92.4
Rheumatology	93.1	88.6	90.8
Surgery	93.7	57.8	93.6
Thoracic surgery	93.8	55.7	93.8
Urology	96.9	16.8	96.9
Vascular surgery	95.1	92.1	94.8

Note: CPOE = computerized physician order entry; EC = electronically created; ES = electronically signed.

third-party payers, whenever possible, was often cited as a key feature.

DISCUSSION

Our case study reveals that an imaging CPOE system with embedded DS can be broadly accepted in clinical practice in all care settings and across all specialties. Rates of CPOE adoption and meaningful use increased significantly over time. Significant variations in meaningful use exist across practice settings and clinical specialties, as well as imaging modalities. Although significant improvement was observed across all practice settings, there were some intergroup differences, with outpatient having the lowest rates of ES and EC orders. This difference is most likely attributable to the large outpatient network of attending physicians affiliated with our institution, in which certain practices continue to have administrative staff members who enter radiology orders for physicians. Constant monitoring and feature modifications based on user feedback can enhance the adoption process, as demonstrated by incremental improvement in adoption and meaningful use associated with feature enhancements.

The meaningful use of health care IT can improve patient safety, efficiency, and the quality of care [23]. Initial studies have showed that with DS, the percentage of low-utility imaging studies may decrease by as much as 57% [24]. Although Vartanians et al [25] showed that a simple change in the business logic of the order entry system may substantially decrease the rate of low-yield

Table 2. Workflow features cited as helpful by users to improve usability of CPOE

- Integrated online scheduling module
- Ability to electronically sign an order from tethered or mobile devices
- Intuitive user interface
- Examination shortcuts with user-specified macros enabling one-click or two-click ordering of commonly ordered examinations
- Elimination of administrative duplicate data entry
- I ntegration of the CPOE system with third-party payers' preauthorization databases to enable automatic preauthorization process when possible
- Real-time decision support

Note: CPOE = computerized physician order entry.

imaging examinations, to the best of our knowledge, no prior studies have examined the adoption and meaningful use of CPOE in radiology in various care settings and across specialties.

Our findings are likely attributable to at least 2 previously described factors affecting health care IT implementation [26]. The first is related to the usability, accessibility, and reliability of the technology application. Changes to the application based on user feedback and feature enhancements to optimize workflow are likely important factors for improving adoption and meaningful use (Table 2). A recent study suggested that ordering providers who create their own orders in a CPOE system are more likely to accept evidence presented by DS and have more appropriate ordering practices [25]. Although such results may simply reflect a correlation between providers who create their own orders and those who are more likely to accept advice, it is possible and even likely that order creation in CPOE with exposure to DS is an independent predictor of a positive response to DS. Further studies would be needed to assess such a hypothesis in various care settings and for different specialties. Our results suggest that with adequate IT integration and workflow optimization, we can engage providers in all care settings or specialties with CPOE for imaging, either at the time of order entry or electronic signature, to create an opportunity for DS to improve quality, safety, and reduce waste.

Clinicians' workflow issues, often clinic and specialty specific, also contribute to CPOE use. In our study, physicians with the lowest rate of meaningful use of EC orders were those who tended to spend a substantial part of their days away from their computers, such as in the operating room or procedural suite. Any processes that negatively affect physicians' workflow are likely to encounter resistance [27]. This reluctance to interrupt their accustomed workflow is the reason gynecologists, orthopedic surgeons, gastroenterologists, and urologists are among the least frequent meaningful users of EC orders for imaging in the CPOE system. However, these providers had high meaningful use of ES orders in the CPOE system, which could serve as a point of DS exposure.

Our case study had several limitations. It was performed at a single academic medical center, and therefore generalizability of the findings to other settings is unclear. Our organization has a history of health care IT innovation, with leadership and a culture that values technology to improve quality and safety. This culture was crucial in encouraging and nurturing early experiments with imaging CPOE. Yet it took years to complete our broad implementation of imaging CPOE. We believed that our study was the first of its kind with respect to the scope of implementation of an integrated imaging CPOE system, so we were deliberate in our implementations to ensure optimized workflow and to minimize user dissatisfaction. It is likely that future implementations at other sites can be performed more rapidly and with greater ease. House staff members at teaching hospitals are often more proficient with new technology, thus enhancing inpatient and ED adoption and meaningful use measures compared to outpatient practices. However, we noted that the use of ES orders was lowest in the inpatient setting, which was most likely due to the high volume of portable chest x-rays performed without correlating electronic orders in the CPOE system. Therefore the lower meaningful use of ES orders for inpatients (89%) reflects a diminished adoption of CPOE in this setting. Meanwhile, we are likely underestimating meaningful use, because we did not provide electronic access to CPOE for providers outside our health care delivery network. Such nonaffiliated providers continued to call our radiology scheduling office and thus were unable to create or sign their orders in the CPOE system. Another limitation was that since 2007, a new hospital electronic CPOE policy requires ordering providers' electronic signatures on orders created by nonphysician proxies, so the increase in electronic signatures and provider creation of orders in CPOE in the later stages of this study do not reflect completely voluntary adoption and meaningful use. We did not formally survey our referring providers throughout the study period to assess their attitudes and satisfaction with the various features. Finally, assessing the clinical impact of CPOE and DS was outside the scope of this study and will be reported separately.

CONCLUSIONS

An imaging CPOE system with embedded DS that is integrated into the health care enterprise IT infrastructure and the relevant electronic medical record platform and optimized within the clinicians' workflow can be successfully and broadly accepted clinically. Such an imaging CPOE system, if adopted and meaningfully used, could create an excellent platform for delivering real-time DS to reduce inappropriate use of imaging, improve quality, and reduce waste.

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